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An experiment of Mulder[*] deserves notice here, as showing the possible existence of a cause of error in the processes made use of both by Rose and Dumas. Mulder dissolved 1 gramme of silver and 0.13 gr. of antimony in nitric acid, added 5 gr. of tartaric acid to retain the antimony in solution, and then determined the silver by precipitation with a standard solution of salt. He obtained 999.125 instead of 1,000, while a similar experiment without the antimony and tartaric acid gave precisely 1,000 silver. Upon what this difference of nearly 0.9 milligr. depended was not ascertained. It is not impossible that a trace of tartrate of silver may be precipitated with the chloride; and if this be so, the chlorine would be estimated too high, whether determined volumetrically, as in the case of Dumas, or by weight, as was done by Rose; and the atomic weight would consequently be found too low.

It appears from the foregoing remarks that recent investigations may be considered as having led essentially to two different numbers for the atomic weight of antimony. That of these numbers, the one, 120, was first deduced by Schneider, and is supported by a single analysis of Professor Rose. That the other, 122.34 is the result of my own observations, subsequently confirmed by the works of Dumas and of Kessler, of which the first differs only by a few decimals from, and the second agrees precisely with, the equivalent previously obtained by me. I have given the reasons which cause me to doubt the correctness of the equivalent assigned by Schneider; I cannot think that three experimenters, working independently of each other and using different processes, would arrive at results so nearly identical, were these results very far removed from the truth.

Five hundred and third meeting.

January 29, 1862. — STATUTE MEETING.

The PRESIDENT in the chair.

The Corresponding Secretary read a letter of acknowledgment from the Corporation of Brown University for a copy of the Memoirs of the Academy, Vol. VIII. Part I.

Dr. John Dean, of Boston, was elected a Fellow, in Class II. Section 2.

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[*] Die Silber-Probirmethode, von G. J. Mulder, (Leipzig, 1859,) S. 165.

Alvan Clark, Esq., of Cambridge, in Class I. Section 2.

Right Rev. John B. Fitzpatrick, of Boston, in Class III. Section 4.

Sir William Fairbairn, of Manchester, England, was chosen a Foreign Honorary Member, in Class I. Section 4, in place of the late Robert Stephenson.

Prof. Treadwell, in a communication upon improvements in heavy ordnance, took occasion to criticise a recent work upon this subject by Captain Rodman, U. S. A.

The work in question is contained in a series of Reports made by Captain Rodman, of his experiments, performed, through a number of years, and at a very great expense to the government, and now printed in a very costly form, but not published, in the usual sense of that word. The experiments had for their ultimate object the improvement of cast-iron ordnance, and more especially to prove the value of a method, devised by Captain Rodman, of cooling the gun from its fluid state. To accomplish this, he restores the old method of casting the gun upon a core, and passes through the axis of this core a stream of cold water. The purpose of this is to produce a more perfect equilibrium of the particles of iron than they possess when the cooling is performed from the outside surface, as is the case when guns are cast solid. This seems to be a good method for casting large guns, and the few experiments that have been made upon proving, to extremity, guns cast in this way, show in its favor. He produces, after all, but a cast-iron gun, and the labors of others, upon other materials, have established the fact that cast-iron guns and round shot are soon to give place to another generation, formed of a different material and upon an entirely different plan. But of this I shall speak hereafter.

The first question now is, whether Captain Rodman's experiments, and the deductions drawn from them, are trustworthy. Now, the whole superstructure which he lays out, and proposes to raise, depends upon an instrument which he has constructed for determining, as he supposes, the actual force of the fluid produced by fired gunpowder under almost all possible circumstances, and the power of cast-iron guns to resist the force thus created without being destroyed by it. This instrument is at once the compass, quadrant, and chronometer by which he is guided in his voyage of discovery. It is described particularly at pages 174 and 175, with a good plate annexed. Plates of it are given likewise, in some modified form, in several other places.

This instrument and its use will be understood by any engineer or intelligent mechanic from the following description. Suppose a row of six small holes to be drilled through the side of a cannon, into its caliber. These holes are placed 14 inches apart, and, commencing near the breech, extend to near the muzzle, or a distance of 84 inches. The instrument consists of a small but strong iron frame, having a shank or plug forged upon one of its sides. This plug is 1½ inches in diameter and 1½ inches long, and is formed into a screw, the thread of which corresponds with a similar screw-thread cut into the outer portion of each of the holes in the side of the gun, by which means the frame may be secured to either of the holes, at pleasure. A small hole is bored through the axis of this plug, making a free passage to the caliber of the gun. A piston is nicely fitted to this hole in the plug, and thus the end of the piston receiving the whole force of the fired gunpowder will be driven outwards at each discharge. A large steel head or block is fitted upon the outer end of the piston, and from this head rises a pyramidal or lozenge-shaped point, or blunt edge. Against this edge, and firmly fixed in the frame, is a piece of thick copper. Now when the gun is fired, the piston, being driven outwards, forces this dull point or edge into the copper, and leaves a mark or impression upon it corresponding in depth to the force with which the piston was driven against it. By comparing an impression, made in this way, with another impression made upon another piece of copper by the actual pressure of weights placed upon a similar tool, Captain Rodman supposes that the force of the piston may be estimated very nearly. It will be seen, on proceeding a little further, that the force of the point, by which the impression is made by the instrument, is not the equivalent of the pressure upon the caliber of the gun, and that it was a gross oversight in Captain Rodman to consider them as equals. It will, of course, be understood, that, when one of the holes is used by the instrument, the others are closed by screw-plugs made to fit them.

Let us, then, see whether the instrument will perform what is claimed for it. First, then, it is said that the indentation or impression made by the blunt or diamond-shaped point indicates the *pressure* of the fired gunpowder; that it acts by *pressure* purely, as a heavy weight acts when placed slowly upon a support, and not by a blow, as the same weight will act when suffered to fall through some sensible space, and certain facts are adduced at page 178 to sustain this view. I shall not stop here to show the fallacies of these supposed analogies, but appeal first to the direct teaching of a simple experiment. Take, then, a little spring balance, such as is used at some of the post-offices for weighing letters, and which consists of a little pedestal and column, like a candlestick, which contains a spiral spring, and over the top is the pan, to hold the thing to be weighed. Now take any weight that will carry the pan just down to the top of the column when slowly applied. Half of this weight will carry the pan half-way down, if applied in the same way, but if you add to this half weight a small quantity, just enough to overcome the friction of the acting parts, and hold this upon the pan when at its full height, so as just to touch its surface, and then release it *suddenly*, the pan will descend to the top of the socket, or will mark twice the weight that it actually possesses. The cause of this must be so apparent to any one well acquainted with the laws of moving forces that I shall not stop to explain it here. Yet the action of the weight here is perfectly analogous to the action of Captain Rodman's instrument, or that part of it which is moved by the powder to make the impression, namely, the indenting tool, the block upon which it rests, and the little piston which receives the force of the powder. The mass of matter of which these are constituted is *fired* against, or into, the copper, as much as the ball is fired out of the muzzle of the gun. The analogy with the experiment of the spring balance is this: the indenting tool and its appendages are pressed forward by the gunpowder. The weight upon the spring balance is pressed down by gravitation. These pressures change the inertia in both cases into living force. This living force accumulates during the motion, from the gravitation in the weight, and the powder pressure in the gun, being, through the first half of the space, twice as great as the mean force of the resistance of the spring in the one case, and the copper in the other; and this accumulation is displayed in overcoming the resistance during a space equal to that first passed over.

We see, then, from the analogy of the weight falling upon a spring balance, that Captain Rodman's instrument ought to display and register double the force which he applies to it; even if it acts as freely and undisturbedly as a spring balance, it cannot make less than a double register. But we shall see by and by that this is but a small part of the actual error; and yet Captain Rodman takes its register as true to within 1,000 pounds in cases, which he supposes to have been of pressure, of 90,000 or 100,000 pounds. He seems, indeed, to have had no suspicion of any error when his instrument gave indications of force wholly incompatible with the strength of the materials to which it was applied. Thus, at page 197, he takes the force which acted upon it at 100,000 to the square inch. Now the instrument in this case was held to the gun by a screw, formed into the cast-iron body of the gun, 1½ inches in diameter and 1½ inches deep. This gives an area of the *plug* of the instrument of 1.75 square inches, which received the full pressure of the fired powder. The pressure upon the end of the instrument then was 1.75 × 100,000 = 175,000 pounds, or about 80 tons. He must be a very bold engineer who would sleep under a weight of 10 tons suspended over him by a bolt tapped into a hole, in a cast-iron plate of 1½ inches in diameter and 1½ inches deep; and yet it does not seem to have occurred to Captain Rodman that 80 tons' pressure must have driven his instrument from its place.

But let us go a step further. Captain Rodman, at page 192 *et seq.*, relates a course of experiments which may be given in short hand as follows. He made 18 cylinders, of three different kinds of iron. They were all one foot long, and all bored out through their entire lengths with calibers two inches in diameter. They were then turned off on their outsides, so as to leave them of six different thicknesses, varying from each other from half an inch up to three inches; the variation being, of course, by increments of half an inch. Each kind of iron gave one cylinder of each thickness. The mean strength of the iron, as ascertained from specimens of each casting, being 26.866, say 27,000 pounds per square inch. These cylinders were then subjected to a bursting force produced by firing gunpowder confined within them. This was done for the purpose of ascertaining the power of cast-iron of these different thicknesses to withstand the force thus produced. The force was measured, by Captain Rodman's instrument, of course, and the first two columns in the following table give the strength of each thickness of metal according to Captain Rodman's mean: —

½	37842	25541
1	38313	38313
1½	63384	46057
2	80229	51085
2½	92270	54732
3	93702	57468

Upon seeing the enormous strength thus given to the iron, Captain Rodman merely remarks that the bursting pressures are greater in the whole series than required by the tenacity of the iron, "even supposing the whole thickness of metal to resist uniformly as in tensile strain." But no doubt seems to cross his mind as to the accuracy of his instrument or his measures; he therefore proceeds forthwith to compute the force on the hypothesis "that the strain diminishes as the square of the distance from the axis increases." This means to reduce the power of the metal to sustain pressure, at different thicknesses, according to Barlow's formula. I have given his numbers in the third column above.

I confess I was puzzled for a long time to find out what these numbers meant. The tenacity of the iron used was 27,000 pounds to the inch; Barlow's formula gives for a cylinder 2 inches in internal diameter and 1 inch thick, made of such iron, just half of this tenacity, or 13,500 pounds. I then went over all the different thicknesses according to Barlow's formula, and found even stronger cases of discrepancy than that here cited; and as I do not profess to be a mathematician of a very high order, while Captain Rodman has the calculus "familiar as his garter," I thought it was possible, after all, that I had misunderstood Barlow's rule. I therefore laid down, in section, each of the cylinders in full size, and requested three of the distinguished mathematicians of Cambridge to tell me what must be the strength of each according to Barlow's rule. They all calculated separately, and all agreed with each other and with me exactly, and I here give the whole matter in a tabular form.

1st column in this table, gives the thickness of the several cylinders.

2d column, the pressure per square inch, as measured by Captain Rodman's instrument, under which each cylinder burst.

3d. The pressure which the cylinders ought to have sustained according to Captain Rodman's computations, from Barlow's formula.

4th. The true pressure of burstings according to Barlow's *formula* as computed and applied by me, on iron having 27,000 pounds per inch tenacity, — this being the mean tenacity of these specimens, as stated on p. 192.

5th. The errors of Captain Rodman's experiments, or of his instrument.

6th. The errors of Captain Rodman's computations.

1	2	3	4	5	6
½	37842	25541	9000	28842	16541
1	38313	38313	13500	24813	24813
1½	63384	46057	16200	47184	29857
2	80229	51085	18000	62229	33085
2½	92270	54732	19286	72984	35446
3	93702	57468	20250	73452	37218

[NOTE. — The reader is requested to attend particularly to the 5th and 6th columns of this table, as these give the errors of the instrument, and of the computations.]

Now how is all this? Why, Captain Rodman in his computations took, not the coefficient of the true tenacity of 27,000, as laid down by Barlow, but the tenacity which his instrument gave for the cylinder one inch thick. Thus taking at 38,313 what should have been 13,500. Not only so, but the law of the inverse square, which he used, and which is Barlow's rule, makes it impossible that any of his last instrumental measures should be nearly right, even if the tenacity be increased from 27,000 up to 76,626, which is the number that he in fact uses. For, according to this law, a cylinder of two inches' internal diameter, made of cast-iron, or any *unmalleable* material, of 76,626 pounds' tenacity, can never be made thick enough to sustain a pressure of 76,626, or at least it cannot be done until some one shall contrive to make $1 \times x = 1 + x$, or 1 multiplied by 1 equal to 1 added to 1, a feat which Captain Rodman's instrument must have performed in giving several of the results above tabulated.

I do not think it will be necessary to pursue this instrument any further to show its utter worthlessness. It must be given up, and the whole family of results born of it must go with it.*

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* I shall be excused for citing one other case, although it may be thought, by some, unnecessary. Captain Rodman gives, at page 197, in his table, the force produced by firing 12.67 pounds of powder in an 11-inch gun, behind a shot of 186.4 pounds' weight, at, in one instance, 100,000 pounds. Now this must have given a *bursting* pressure upon the walls of the gun of 1,100,000 pounds to every inch of its length; consequently, if the gun was 11 inches thick, the iron to sustain this pressure must, if Barlow's formula be true, (and Captain Rodman makes no

I shall pass, therefore, from Captain Rodman's instrument to an examination of his gunpowder. When the newspapers, some time ago, gave the story of Captain Rodman's experiments with his 15-inch gun, there was a great account made of the strange kind of gunpowder used, the grains of which were said to be as big as pigeons' eggs. But Captain Rodman's book gives us the reason for the use of this very coarse powder. It is to avoid the great stress laid upon the gun by the rapid development of the gas or fluid, as produced by powder of common grain, from its quick combustion. Now, Captain Rodman proposes, by the slow combustion of these large lumps, not only to avoid the shock of the first explosion, but to continue the development of the force through the whole length of the bore. This would certainly make it much easier work for the breech portion of the gun; but the fact of resorting to it shows the suspicion entertained by Captain Rodman of his gun's strength.

Let us, then, first see how far the idea of equalizing the pressure is obtained by increasing the size of the grain. To do this, I must resort to the measures given by Captain Rodman's instrument, which, though worthless as absolute measures, may yet give some rude approximation to comparative values when used upon the same gun and upon the same place, but with different grained powders. Turning to his book, then (p. 203), we find that a charge of 8 lbs. of powder grained to .1 of an inch diameter, gave against a 43-lb. shot a force of 51,800 lbs., 14 inches from the breech, and 6,700 lbs. at the distance of 84 inches, — these being the greatest and least forces; while a charge of 8 lbs. of powder of .4 inch grain, or 64 times the former in size of grain, gave against the same shot 31,950 lbs. for the greatest, and 5,150 lbs. for its least force. The greatest force of the fine powder, then, was about 7 times that of the least force; while the greatest force of the coarse powder was about 6 times that of the least force. Surely this is no

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doubt of that, but uses it, under the name of the inverse square,) have possessed a tenacity of 150,000 pounds to the inch. Not only will no cast-iron bear this strain, but no metal, nor any other substance whatever yet known to the art of man, is capable of bearing it. Even cast-steel, the strongest body known, when wrought down by the best hammering, will not sustain 150,000 pounds to the inch. Indeed, if a mass of iron gun-metal, though the strongest ever made, were cast as large as the Capitol at Washington, and then bored through with a caliber of 11 inches, it would, according to Barlow's formula, be split by a fluid pressure of, not 150,000, but 50,000 pounds to the inch.

great advance in equalizing the forces between the breech and the muzzle of the gun. But let us see what it costs in loss of force from the use of the coarse powder. Taking the mean of these two extremes as the true force in both cases, we have $51{,}800 + 6{,}700 \div 2 = 29{,}250$ for the mean force of the 8 lbs. of fine powder, and $31{,}950 + 5{,}150 \div 2 = 18{,}550$ for the mean force of the large powder; from which it will be seen that it will require 12½ lbs. of the coarse powder to produce the same force upon the shot that is produced by 8 lbs. of fine powder. The long and short of this whole matter of using the powder in lumps rather than grains is a *mechanical adulteration*, and produces the same effect, namely, a slow combustion, such as may be produced by making the powder of materials *chemically adulterated*, or by mixing a portion of clay with the paste, or by moistening good powder before using it. This reduction of force may be carried to any extent by increasing the size of the grains or lumps, or by making it in *perforated* cakes, as Captain Rodman actually proposes to do.

But suppose that Captain Rodman's ideas of the advantage of a slow development of the force could be carried out, of what use would it be? I assert, although I am not yet quite prepared with a formal demonstration of it, that the same, or very nearly the same, quantity of iron will be required in the gun, the iron being used in the manner pointed out by me in 1855, to give the same velocity to a given shot, under whatever law the force is developed, between the limits of the quickest powder now used, and one of equable force development; and that, to produce this force with the least expenditure of powder, the development of the force should be made as quick as possible.

I now pass to an examination of Captain Rodman's proposal to use hollow shot. Having, as it seems to me, laid his powder under as great a contribution as it would bear, to avoid putting too much stress upon his gun, he proceeds to put the same tax upon his shot, and he assesses it by taking 9 inches from the heart of every 15-inch shot, thus reducing its weight from about 425 pounds to about 320 pounds. In the mediæval times, when guns and gunnery were in their infancy, stone balls were used. The lightness of this material saved the imperfect *bombards* from destruction. The effect of these balls was of course very small, compared with the heavy, solid iron shot brought into use in a later age. Are we to return to the mediæval practice? This certainly seems a step in that direction.

Sir Howard Douglass, in speaking of the terrible effect of the fire of the American frigates in the war of 1812, says that some of them used shot weighted by a leaden core. This I believe is not true, but it shows the opinion of this old engineer, of the advantage that might be expected from increasing rather than diminishing the specific gravity of cannon-shot. Yet Captain Rodman's hollow shot seems to be looked to (pp. 289, 307) as the missile to meet iron-plated ships. Whether it is intended to explode them against the ship, or to depend upon their direct percussion, is not very clearly stated. The effect would probably be very much alike in both cases. Indeed, Captain Rodman admits (p. 298), that, although "none of these broke in the gun, some did break in the sand-bank after the sand had been packed hard by repeated firing." God forbid, then, that we should ever have to try them against the sides of the Gloire or the Warrior.

I have thus examined some of the prominent points in the labors of Captain Rodman, as they are detailed in his reports; and, without, as I hope, making any remark disrespectful to him as an officer and gentleman, I have declared freely what seems to me the value of the most important of the experiments and conclusions given in his work. Repeating here what I declared in an earlier part of this paper, that I think well of his method of cooling the hollow casting which is to form a gun, I think that there is good reason to believe that these guns will be somewhat superior to those made in the usual method. In the practice of casting in this way, however, great care must be observed to avoid the explosion which may occur should the cooling water find its way from its conductor into the body of the mould.

Five hundred and fourth meeting.

February 11, 1862. — MONTHLY MEETING.

The PRESIDENT in the chair.

The Corresponding Secretary read letters of acceptance from the Right Rev. Bishop Fitzpatrick and Dr. John Dean, recently elected Fellows, and from John M. Ordway, elected Associate Fellow of the Academy.

Professor Peirce, from the Committee to which the subject was referred, made a report upon the work of Capt. Humphreys and Lieut. Abbot, U. S. Topographical Engineers, upon the Mississippi River and the best mode of protecting its